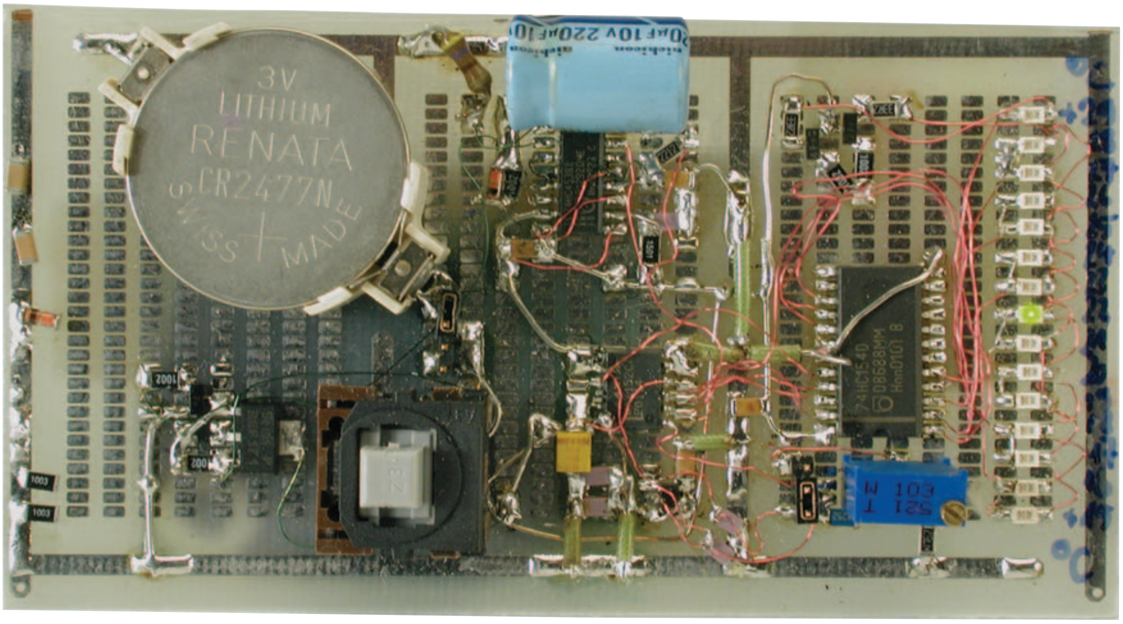
ROOM THERMOMETER

Gregor Kleine



Just add an A/D converter and a few discrete LEDs to this temperature sensor chip and you get a simple thermometer. This application builds an accurate and stable thermometer displaying room temperature with a resolution of 1 °C.

The MAX6610 from MAXIM is a relative newcomer to the field of temperature sensing IC's. The chip has a built-in voltage reference and an analogue output scaled to simplify integration with an 8 or 10-bit A/D converter (see textbox). A simple room thermometer does not usually require such precision and we run a risk of being accused of using a sledgehammer to crack a nut but the chip is quite versatile and this application provides a useful introduction to some of the features of the device. For more information on this device see the inset.

The complete room thermometer block diagram is shown in **Figure 1.** The MAX6610 precision temperature sensor outputs an analogue signal that's linearly proportional to temperature. The signal is converted into a digital value by the 8-bit MAX152 analogue to digital (A/D) converter. Only five bits of the output byte are used by the decoder to light a single LED to indicate room temperature. Finally two monostables (monoflops) are used to generate all the timing signals necessary to control events in the circuit. The first produces the conversion signal to the A-D converter while the second controls a MOSFET in the power supply line to maintain power to the

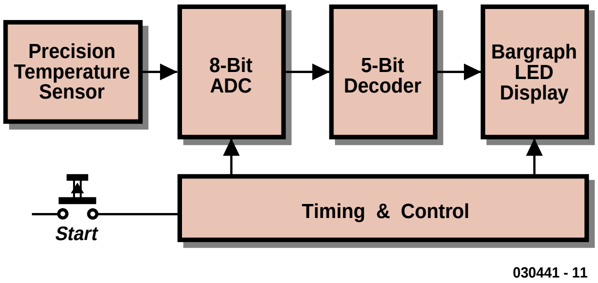


Figure 1. The room thermometer block diagram.

circuit during the measurement process. After an adjustable period it switches the thermometer off. It is only necessary to press S1 briefly to activate the circuit and the temperature will be displayed for a few seconds.

On closer inspection

Figure 2 shows the complete circuit diagram of the room thermometer. IC1 contains the temperature sensing element and can be used in the temperature range from –40 °C to +125 °C. The sensor contains an on-board reference so that it does not require any calibration and is designed to interface with an analogue to digital (A-D) converter. It outputs a reference voltage of 2.560 V from pin 5. Pin 4 is the analogue TEMP output; the voltage level at this pin is proportional to temperature. If an 8-bit A-D converter is used to produce a digital value each single bit change corresponds to exactly 1° C temperature change. With a VREF of 2.560 V and an 8-bit A-D converter each bit change of the output is equal to an input change of 10 mV. IC1 produces an output signal with a characteristic of 10 mV/K with a DC offset of 0.750 V. The voltage V_{TEMP} is given by:

$$V_{TEMP} = 750\ \text{mV} + T \times 10\ \text{mV}$$

(with T in °C)

Table 1 shows the output from an A-D converter represented as decimal (dec) hexadecimal (hex) and binary (bin) values.

The sensor will be used at room temperatures so it is not necessary to display the complete temperature range. Table 1 shows that we only need to look at the least significant five bits at the output of the ADC if the displayed temperature range is limited from +5 °C (0101 0000) to +36 °C (0111 1111). The codes between these temperatures are not repeated. **Table 2** lists the digital output values for temperatures within this range.

Each degree is represented by a single LED so a total of 32 LEDs are required if a temperature range of 32 degrees is to be displayed. A 4 to 16 way decoder is used to decode bits D1 to D4 from the output f IC2. The least significant bit, D0, is used to switch either transistor T3 or T4, these drive two columns of eight LEDs. T4 is conducting when D0 output is low while T3 conducts when D0 is high. This arrangement effectively produces a 5 to 32-way decoder function. Only one of the green LEDs will be lit at any one time so current limiting on each column can be performed by a single resistor (R6 and R7).

Although the decoding is available to display a temperature range of 32 °C this can be reduced by simply omitting any LEDs that are not required. The circuit diagram shows just 15 LEDs fitted to display a range from +15 °C to +29 °C. Any other range can be chosen providing it falls within +5°C to 36°C.

Table 1. Correlation between temperature, sensor output voltage and digitised measurement value.

Temperature	V_{TEMP}	ADC_{dez}	ADC_{hex}	ADC_{bin}
–40 °C	0.350 V	35	23	0010 0011
–20 °C	0.550 V	55	37	0011 0111
–10 °C	0.650 V	65	41	0100 0001
–5 °C	0.700 V	70	46	0100 0110
0 °C	0.750 V	75	4B	0100 1011
+5 °C	0.800 V	80	50	0101 0000
+10 °C	0.850 V	85	55	0101 0101
+15°C	0.900 V	90	5A	0101 1010
+20 °C	0.950 V	95	5F	0101 1111
+25 °C	1.000 V	100	64	0110 0100
+30 °C	1.050 V	105	69	0110 1001
+35 °C	1.100 V	110	6E	0110 1110
+40 °C	1.150 V	115	73	0111 0011
+50 °C	1.250 V	125	7D	0111 1101
+80 °C	1.550 V	155	9B	1001 1011
+100 °C	1.750 V	175	AF	1010 1111
+125 °C	2.000 V	200	C8	1100 1000

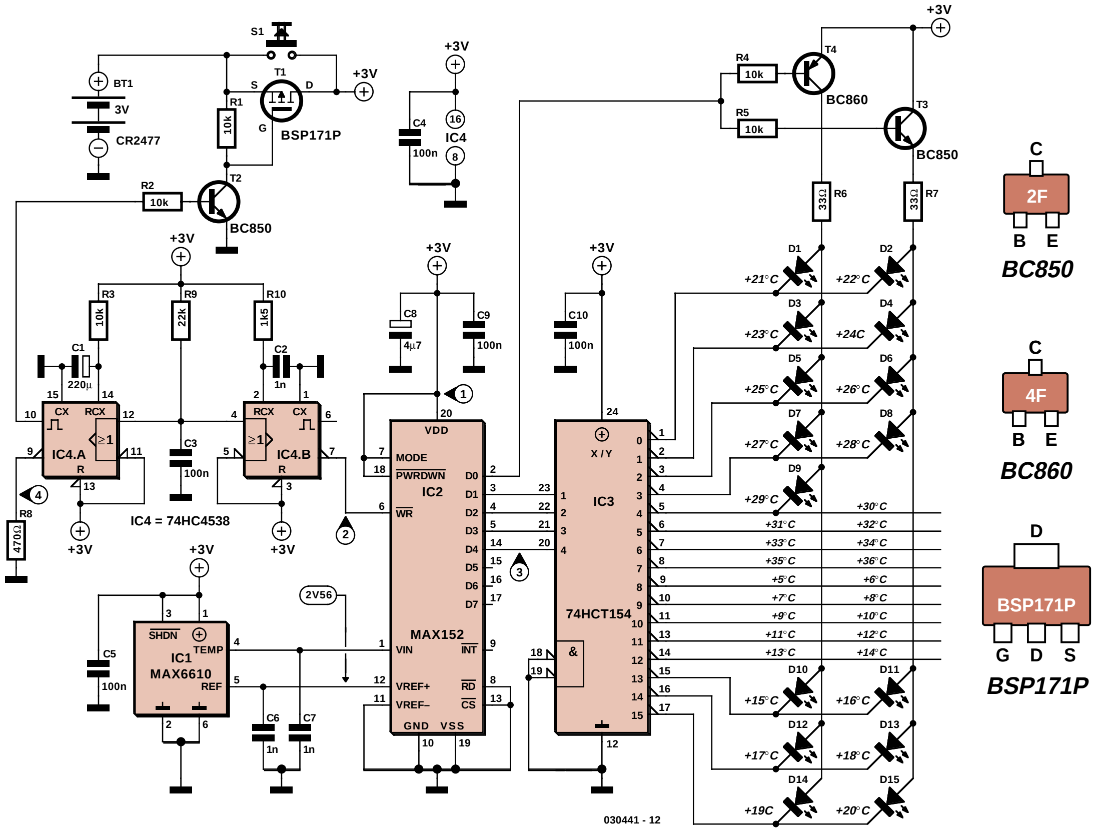


Figure 2. The circuit diagram showing test points and voltage levels.

Table 2. Digitised temperature values within measurement range.

Temperature	V_{TEMP}	ADC_{bin}	T3 / T4	IC3
+5 °C	0.800 V	0101 0000	T4	Q8
+6 °C	0.810 V	0101 0001	T3	Q8
+7 °C	0.820 V	0101 0010	T4	Q9
+8 °C	0.830 V	0101 0011	T3	Q9
...	...	...	...	...
+17 °C	0.920 V	0101 1100	T4	Q14
+18 °C	0.930 V	0101 1101	T3	Q14
+19 °C	0.940 V	0101 1110	T4	Q15
+20 °C	0.950 V	0101 1111	T3	Q15
+21 °C	0.960 V	0110 0000	T4	Q0
+22 °C	0.970 V	0110 0001	T3	Q0
+23 °C	0.980 V	0110 0010	T4	Q1
+24 °C	0.990 V	0110 0011	T3	Q1
+25 °C	1.000 V	0110 0100	T4	Q2
+26 °C	1.010 V	0110 0101	T3	Q2
....	...	...	...	...
+31 °C	1.060 V	0110 1010	T4	Q5
+32 °C	1.070 V	0110 1011	T3	Q5
+33 °C	1.080 V	0110 1100	T4	Q6
+34 °C	1.090 V	0110 1101	T3	Q6
+35 °C	1.100 V	0110 1110	T4	Q7
+36 °C	1.110 V	0110 1111	T3	Q7

Temperature sampling

The MAX152 (IC2) 8-bit A-D converter operating from a +3 V supply is used to digitise the analogue output voltage from IC1. A logic low on the read input ($\overline{RD}$, pin 8) and the chip select input ($\overline{CS}$, pin 13) configures IC2 to stand-alone mode so that a pulse at the $\overline{WR}$ (pin 6) input will cause the converter to sample the analogue input voltage and output its digital value. The digital data is valid approximately 2 µs after the rising edge of the $\overline{WR}$ pulse. **Figure 3** shows the timing diagrams corresponding to the numbered test points on the circuit.

Pressing S1 switches power to the circuit and starts the temperature measuring process. The monoflop IC4.B supplies the $\overline{WR}$ pulse to the A/D converter but the start of this pulse is delayed (T1 ≈ 500 µs) by C3 and R9 to allow the temperature sensor (IC1) to stabilise before its output is sampled. The $\overline{WR}$ pulse width (T2 ≈ 1 µs) is governed by R10 and C2. The conversion time (T3) of IC2 is approximately 2 µs so the output signals to the decoder (IC3) and transistors T3/T4 will be stable after a total time of T1+T2+T3

Author profile

Gregor Kleine (41) has been a development engineer with a well-known Munich-based test equipment manufacturer for the past 10 years. He is currently designing signal generator equipment for the RF spectrum up to 6 GHz used mainly for digital TV testing. He graduated from Aachen Technical University in 1989. He has contributed many articles both analogue and digital for Elektor Electronics in the past 20 years and has also penned many informative articles on communication technology including Digital TV, ADR, ADSL, UMTS and Bluetooth.

(503 µs). This time period is so short that any LED that may incorrectly light during this period should go unnoticed. The trigger for monoflop IC4.A is also produced by the C3/R9 network during power-up and generates a 3-second pulse (pin 10) to switch transistor T2 and MOSFET T1. The MOSFET is connected in parallel to S1 so the pushbutton can be released and monoflop IC4.A ensures that the circuit will stay powered for about 3 seconds.

Resistor R8 discharges the supply at the end of the timing period to ensure that the supply voltage falls to zero relatively quickly when the circuit switches off (**Figure 3**). At the end of the 3-second measurement period the inverting output of IC4.A (pin 9) will go high and residual charge in the supply is discharged through R8. This ensures that the circuit will be ready to take another temperature reading again relatively quickly after each measurement cycle is completed. (030441-1)

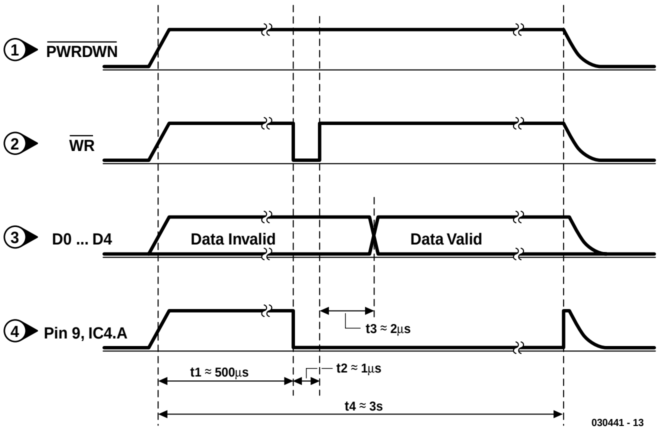


Figure 3. Timing waveforms at the circuit test points.

A precision temperature sensor

The MAX6610/MAX6611 is a temperature sensor with a built-in voltage reference. The digital output is conveniently scaled so that when it is connected to an 8-bit A/D converter the LSB of the output is equivalent to 1 °C change of temperature. With a 10-bit A/D the output LSB is equal to a temperature change of 0.25 °C. The reference output features a proprietary temperature-coefficient, curvature-correction circuit and laser-trimmed thin film resistors that result in a maximum temperature coefficient of 50 ppm/°C and an initial accuracy of ±0.5 %. During normal operation the maximum current consumption is 250 µA, this is reduced to 1 µA in shutdown mode. The supply voltage range is 4.5 V to 5.5 V for the MAX6611 and 3.0 V to 5.5 V for the MAX6610.

The MAX6610/MAX6611 reference output voltage can be used by an external A/D converter. It can supply a maximum of 1 mA with a maximum loading capacitance of 1 µF. The reference voltage has been chosen so that if an 8-bit A-D converter is used each step value of the digital output represents a 10-mV change of the analogue input voltage. A 10-bit A-D converter will offer greater resolution with each step in output representing 2.5 mV change of the analogue input.

The analogue temperature output voltage is a linear function of the chips die temperature:

V_{TEMP} = 1.2 V + (T°C × 16 mV/°C) [MAX6611]

V_{TEMP} = 0.75 V + (T°C × 10 mV/°C) [MAX6610]

The slope of the output voltage is equal to $V_{REF}/256$ per °C (16 mV/°C for the MAX6611 and 10 mV/°C for the MAX6610). The MAX6610/MAX6611 have an active low shutdown input ($\overline{SHDN}$). In this mode the reference voltage is pulled to ground via a 150 kΩ resistor and the TEMP output is switched into a high impedance state. Current consumption in this mode is less than 1 µA. $\overline{SHDN}$ should be connected to V_{CC} if this feature is not needed.

If the MAX6610/MAX6611 is used to measure the temperature of an active component for example, the chip must be mounted in close proximity to or on that component. There is a good thermal path between the sensing element in the chip and its external pins, this ensures that the device will accurately measure the temperature of the PCB on which it is mounted.

The MAX6610/MAX6611 is a low-power device and the self-heating effect produced by its own power dissipation is negligibly small.